THE OHIO STATE UNIVERSITY

THE UTILIZATION OF SILICOFLAGELLATES FOR PALEOTEMPERATURE DETERMINATIONS IN THE SOUTHERN OCEAN

Department of Geology and Mineralogy

by

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ABSTRACT OF THESIS

The Utilization of Silicoflagellates
for Paleotemperature Determinations
in the Southern Ocean

by

Frederick R. Myers

Using the relative abundance of the two silicoflagellate genera, _Dictyocha_ and _Distephanus_, for paleotemperature inferences has failed in the past to yield quantitative results. One of the principle reasons this method has been unsuccessful quantitatively is that discrepencies exist as to the exact temperature range assigned to particular generic abundances. This may be attributed to: 1) differences in the techniques used to obtain the silicoflagellates used as the data base, i.e., surface sediment data vs. surface water plankton samples and 2) other environmental factors in addition to temperature may affect the relative generic abundances.

This study, based on cores collected between Wilkes Land, Antarctica and Australia, relates other environmental factors in addition to temperature to the relative abundance of _Dictyocha_ and _Distephanus_ in Recent surface sediments. These other factors include

mean annual salinity and the mean annual oxygen level in the surface water. All variables were interpreted graphically and statistically to determine their relative importance.

All of the variables behave in a similar manner in this area. They remain fairly consistent with latitude in the Antarctic water mass south of the Antarctic Convergence and change with latitude in the subantarctic water mass north of the Antarctic Convergence. *Distephanus* is dominate south of the Antarctic Convergence where mean annual surface water temperatures range from $-0.5^{\circ}C - 5.0^{\circ}C$, mean annual salinity is constant at 33.90 ^{o}/oo, and the mean annual oxygen level range from 7.0 ml/l - 7.75 ml/l. *Dictyocha* is dominate north of the Antarctic Convergence and increases with latitude as mean annual surface water temperatures increase from $7.5^{\circ}C - 13.5^{\circ}C$, mean annual salinity increases from 33.90 ^{o}/oo - 35.00 ^{o}/oo, and mean annual oxygen decreases from 7.25 ml/l - 6.00 ml/l.

To determine the relationship between the environmental variables and the relative generic abundance of silicoflagellates, a *Dictyocha*/*Distephanus* ratio was calculated for each core area and plotted against the mean annual surface water temperature, salinity, and oxygen. Because of the effect of the Antarctic Convergence, a curved relationship exists between the *Dictyocha/Distephanus* ratio and the environmental factors.

A multiple regression analysis was used as a statistical method to help quantify the data by providing coefficients for a multiple regression equation to be used for surface water temperature predictions. This equation accounts for the effects of all of the variables, therefore, any factor which influences the silicoflagellates assemblage will be measured in this equation. The *Dictyocha/Distephanus* ratio was used as the dependent variable and the mean annual surface water temperature, salinity, and oxygen were used as the independent variables.

The resultant equation successfully predicts mean surface water temperatures usually to within $\pm 2.0^{\circ}C$ of the observed values. However, for this equation to be useful quantitatively with confidence for paleotemperature determinations, it needs to be refined by obtaining additional base data.

INTRODUCTION

A number of investigations have established a correlation between the relative abundance of two genera of silicoflagellates, *Dictyocha* and *Distephanus*, with temperature. Gemeinhardt (1934) noted *Dictyocha* has a preference for warmer water and *Distephanus* has a preference for colder water. Since this discovery, attempts have been made to use this observation for paleotemperature determinations.

Jendrzewski and Zarillo (1971) related the percent of the genus *Dictyocha* in a silicoflagellate assemblage in a sub-Antarctic core to relative temperature. Martini (1971) related the absolute surface water temperature to the ratio of silicoflagellate species *Dictyocha fibula* to *Distephanus speculum* in the Pacific Ocean. The studies mentioned above give qualitative results and are useful only for warm and cold trends.

Mandra (1958) attempted the construction of a quantitative temperature curve using the ratio of *Dictyocha*/*Distephanus* as a function of temperature. The data he used were collected by Yanagisiwa (1943) off the

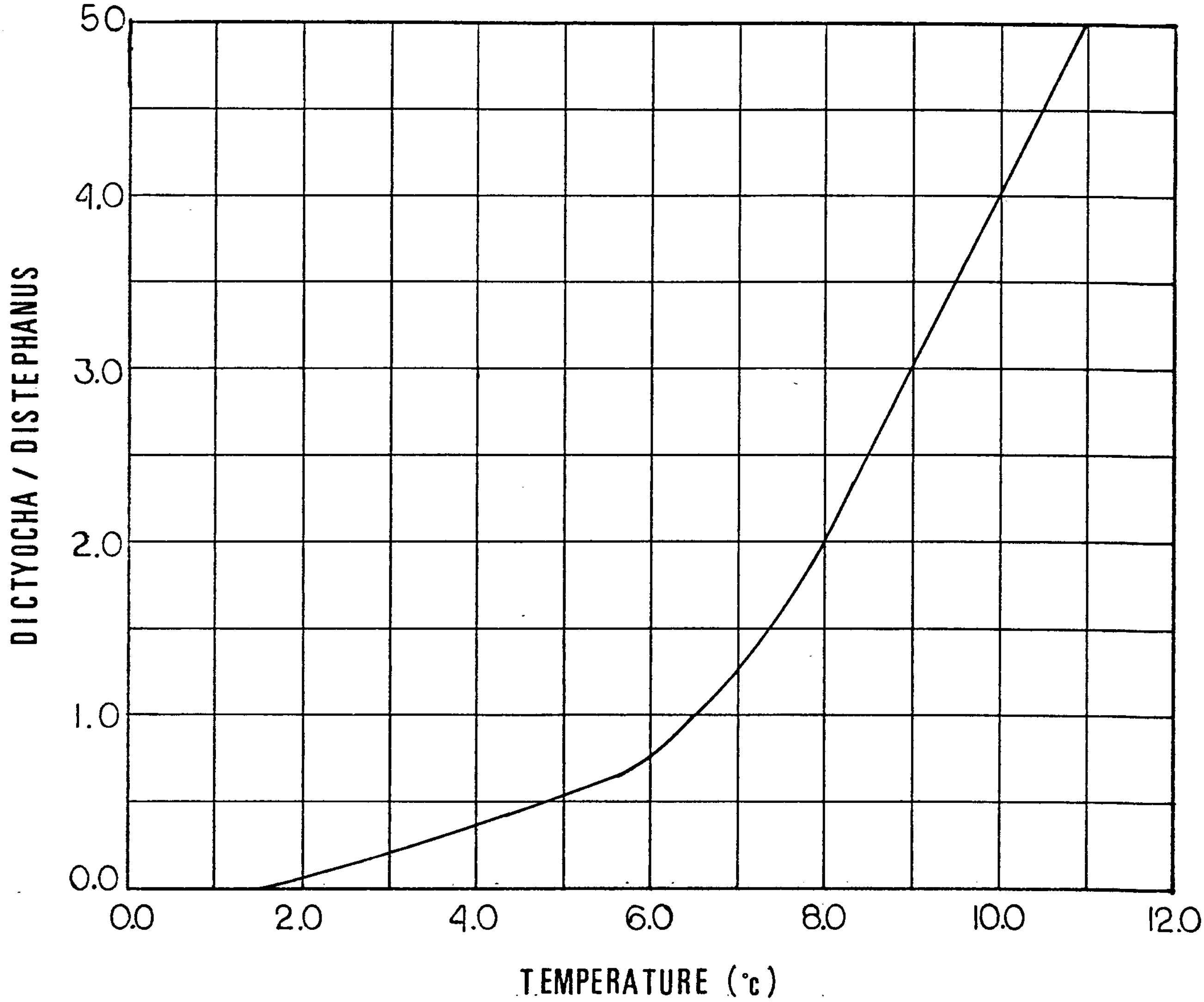

Figure 1: Silicoflagellate Paleotemperature Curve for the area between Wilkes Land, Antarctica and Australia. (Redrawn from Ciesielski, 1974)

coast of Japan and consists of surface water plankton samples and surface water temperature measurements. Mandra and a few others have used this curve for paleotemperature determinations for several sedimentary deposits throughout the world. Mandra's curve has been found to correlate generally with temperature trends predicted by other paleoclimatic indicators, such as nannoplankton and diatoms, (Burky and Foster, 1973; Ciesielski, 1974). However, Ciesielski and Weaver, (1974) found the paleotemperatures derived from utilizing Mandra's curve to be high in Pliocene Antarctic piston cores. Poechlau (1974) studied the relative abundances of silicoflagellates species in the North Pacific and noted that the observed temperature is 10°C to 15°C higher than that predicted by using Mandra's curve. He also noted the area with the least discrepancy is near the Japanese coast where the data were obtained. The low temperatures generated by this technique may be caused by using plankton samples in a near shore environment as a data base. If this is the case, then a recalibration of the generic ratio-temperature relationship in the open marine environment is needed.

Ciesielski (1974) attempted to recalibrate the generic ratio-temperature relationship for the area between Wilkes Land, Antarctica and Australia by relating mean annual surface water temperature to the *Dictyocha*/*Distephanus* ratio in underlying surface sediments. The resulting temperature curve he constructed is shown in(Figure 1). He used this curve to infer Pliocene paleoclimatic conditions based on numerous piston and drill cores taken in the area. Ciesielski, (1974); Ciesielski and Weaver, (1974) used this technique only to define climatic trends and hesitated using absolute temperatures because of the need to evaluate the influence of other environmental factors (Ciesielski, personal communication).

The relative generic abundance of silicoflagellates may also be controlled by other environmental parameters aside from temperature; such as oxygen concentration, salinity, and nutrient supply. Therefore, in any attempt to use silicoflagellates as a paleoclimatic indicator, the influence of these other environmental factors must be evaluated. A technique that would take other ecological factors into consideration may be achieved by using a multiple regression analysis. This type of statistical analysis will provide a multiple regression equation that can approximate a temperature curve from the data of several different variables. Thus, several environmental factors can be intergrated into a single equation and their possible effects accounted for.

Poechlau (1974) made use of multiple regression analysis to obtain coefficients which were used in Imbrie and Kipp's "transfer function" equation. This equation expresses water temperature in terms of varying proportions of species variables, (Poechlau, 1974). He predicted to within $\pm 2.0^{\circ}C$ the surface water temperatures from relative silicoflagellate species abundances in surface sediments in the North Pacific. However, this analysis uses temperature as the dependent variable and does not take into account other environmental parameters.

The purpose of this study is: 1) estimate the effects salinity, oxygen and temperature have on the relative abundance of the two silicoflagellate genera, *Dictyocha* and *Distephanus*, for the area between Wilkes Land, Antarctica and Australia and 2) derive a multiple regression equation that will accurately predict surface water temperatures from *Dictyocha*/*Distephanus* ratios for use in paleoclimatic studies. In addition to temperature, this equation will include salinity and oxygen as independent variables.*

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*Nutrient information is not available.

METHOD

Because living silicofalgellates in the surface water are subject to environmental conditions or seasonal changes that may temporarily affect their relative generic abundances, the use of data derived from silicoflagellates in surface water may be misleading in temperature correlations. Surface sediment samples will reflect the average silicoflagellate assemblage in the overlying water mass over a period of time; therefore, it is preferable to use surface sediment silicoflagellate data rather than surface water plankton data in the examination of the relative generic abundances of silicoflagellates.

Forty-one USNS Eltanin Trigger and Phleger surface sediment cores taken at 1 or 2 degree intervals from 64^{o}S to 39^{o}S latitude between Wilkes Land, Antarctica, and Australia were used in this study (Figure 2). Smear slides were made for each core number shown in Figure 2, and an optimum number of 200 silicoflagellates was counted for each surface core sample.* To ensure an accurate count, 400X magnification was used for most slides, but 100X was used if the sediment on the slide was sparse.

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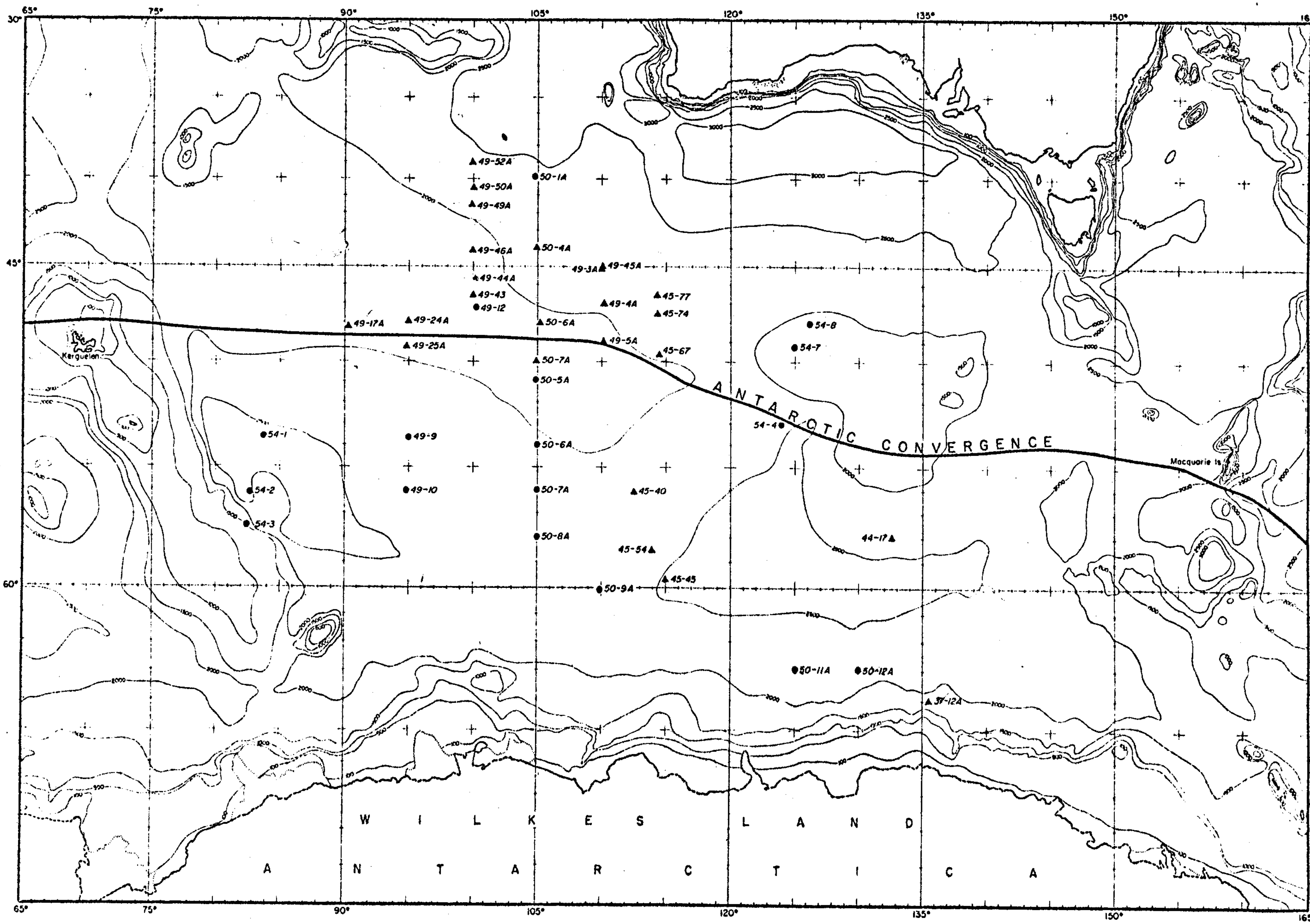
*Because of a lack of sediment material or extreme sparseness in the silicoflagellate assemblage, 200 silicoflagellates could not always be counted.

A Dictyocha/Distephanus ratio was calculated for each core sample, and these were plotted against the annual mean surface water temperature, annual mean surface water salinity level, and the annual mean surface water oxygen level, (from Gordon and Goldburg, 1970). This was done to determine the direct relationship between the ecological variables and the Dictyocha/Distephanus ratio. The Dictyocha/Distephanus ratio, mean annual surface water salinity, oxygen and temperature were first plotted against latitude to illustrate the relationship of each factor with latitude.

A stepwise multiple regression was then performed and a paleotemperature equation was written from the resulting coefficients.

Figure 2: Location Map of Eltanin Trigger (Triangles) and Phleger (circles) Cores Utilized in Determining Surface Sediment *Dictyocha/ Distephanus* Ratios.


ANTARCTIC CONVERGENCE
WILKES LAND
ANTARCTICA
Kerguelen
Macquarie Is.
49-52A
49-50A
49-49A
50-1A
49-46A
50-4A
49-3A
49-45A
49-44A
49-43
49-12
49-4A
45-77
45-74
49-17A
49-24A
50-6A
49-25A
49-5A
45-67
50-7A
50-5A
54-8
54-7
54-4
54-1
49-9
50-6A
54-2
49-10
50-7A
45-40
54-3
50-8A
45-54
44-17
50-9A
45-45
50-11A
50-12A
37-12A

POSSIBLE SOURCES OF ERROR

The effects of some ecological and environmental factors on the geographic distribution of living silicoflagellates cannot be evaluated in this analysis of surface water death assemblages. Such factors include storms, seasonal blooms of a particular genus, and differential grazing of predators. The *Dictyocha*/*Distephanus* ratios were determined from surface sediment samples because they reflect an average silicoflagellate assemblage in the surface water. Plankton samples were unavailable but would likely indicate the sources of error mentioned above.

Possible unrepresentative surface sediment *Dictyocha*/*Distephanus* ratios will be the result of factors that affect the silicoflagellate skeleton after the death of the organism. Three possible sources of error in the use of silicolfagellates for temperature inferences are:

(1) Reworked sediments. The sediment from which the cores were taken have to be Recent in age or the silicoflagellate assemblage will not reflect surface water isotherms. Ciesielski (1974) examined diatom zones and available paleoclimatic data and confirmed the Recent age of the sediments.

(2) Latitudinal spreading of skeletons. The principle current in the area, the West Wind Drift, flows predominately from west to east; therefore, spreading will be longitudinal and should not be a significant source of error.

(3) Differential Dissolution. The test of *Dictyocha* and *Distephanus* are nearly the same thickness and overall size (Lipps, 1970). Unless a chemical difference exists between the tests of the two genera, or the tests have a structural difference, dissolution should affect both genera equally. A controversy exists as to whether differential dissolution occurs as the silicoflagellate skeleton settles through the water column. Some investigators claim differential dissolution exists between the genera while others claim it doesn't. If differential dissolution does occur, then any paleotemperature equations for Plio-Pleistocene sediment studies based on planktic ratios of *Dictyocha* and *Distephanus* would be in error in proportion to the amount of differential dissolution. However, differential dissolution should not affect calculated *Dictyocha*/*Distephanus* sediment ratios to surface temperature relationships because these ratios are correlated to temperature after dissolution modification, rather than prior to dissolution as in the case of surface water plankton-temperature correlations. Changes in the relative dissolution of the genera through time would however be a possible source of error.

ANALYSIS OF *DICTYOCHA/DISTEPHANUS* RATIO, TEMPERATURE, SALINITY, AND OXYGEN RELATIONSHIPS

Fluctuations of Individual Variables With Latitude

Dictyocha is generally absent south of 56°S latitude (Figure 3). This genus appears north of 56°S latitude, and its numbers increase slightly to the Antarctic Convergence, a major oceanic boundry where northward-moving Antarctic waters meet sub-Antarctic waters and sink below them causing radical environmental changes which affects sea and bird life. The Antarctic Convergence occurs at approximately 49°S latitude in this area, and the *Dictyocha/Distephanus* ratio jumps from approximately 0.50 south of the Antarctic Convergence to 1.00 - 1.50 just north of it. The *Dictyocha/Distephanus* ratio increases much more rapidly north of the Antarctic Convergence than south of it. There is an increase in the ratio from 0.00 at 64°S latitude to approximately 0.50 at 49°S latitude, whereas the ratio increases from approximately 1.00 - 1.50 at 48°S latitude. To 6.7 AT 39°S lat

The annual mean surface water temperature increases at a constant rate south of the Antarctic

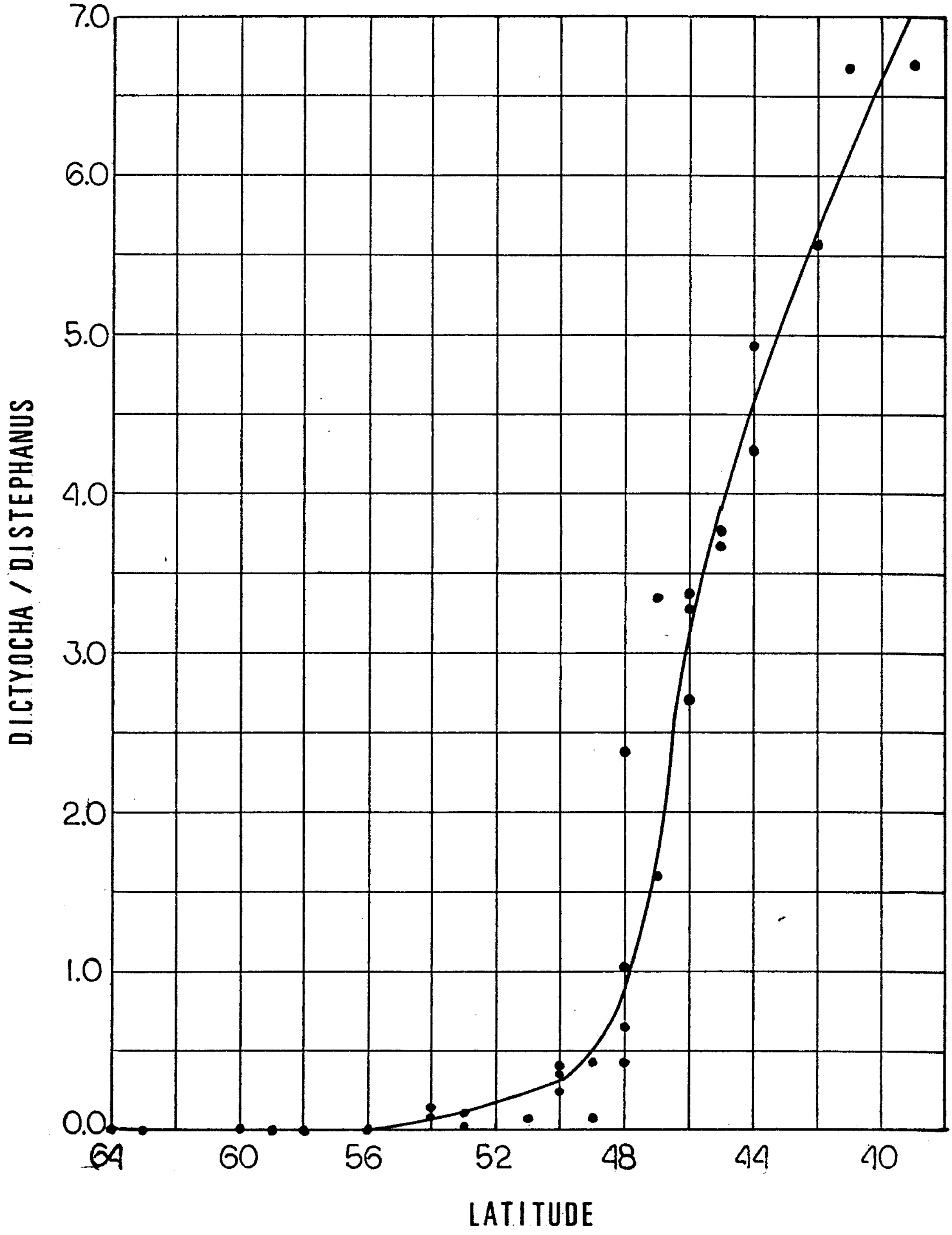


Figure 3: Surface sediment Dictyocha/Distephanus ratio as a function of latitude.

Convergence (Figure 4). It increases from $-0.50^{\circ}C$ at $64^{\circ}S$ latitude to $5.00^{\circ}C$ at $49^{\circ}S$ latitude. The temperature jumps a few degrees over the Antarctic Convergence to 7.0 - $8.0^{\circ}C$*, then it increases at a more rapid rate with latitude to $13.5^{\circ}C$ at $39^{\circ}S$ latitude.

The annual mean oxygen level stays fairly constant at approximately 7.75 ml/l south of the Antarctic Convergence and decreases with latitude north of the Convergence (Figure 5). It decreases 0.75 ml/l over the Antarctic Convergence to 7.0 ml/l. North of the Antarctic Convergence, the mean oxygen level decreases at a constant rate with latitude from 7.0 ml/l at $50^{\circ}S$ latitude to 6.25 ml/l at $39^{\circ}S$ latitude.

The annual mean salinity level also remains at a constant level south of the Antarctic Convergence, has a jump over the Convergence, and continues to increase in a linear pattern to the north (Figure 6). South of $50^{\circ}S$ latitude the mean salinity level stays constant at 33.00 $^{\circ}/oo$. It jumps approximately 0.20 $^{\circ}/oo$ over the Antarctic Convergence and continues to increase with latitude to 34.90 $^{\circ}/oo$ at 39° latitude.

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*Because the core samples are taken from a wide area longitudinally, the sharp jump in the temperature is not readily noticeable. However, if the individual tracks are studied, then the jump can be seen graphically.

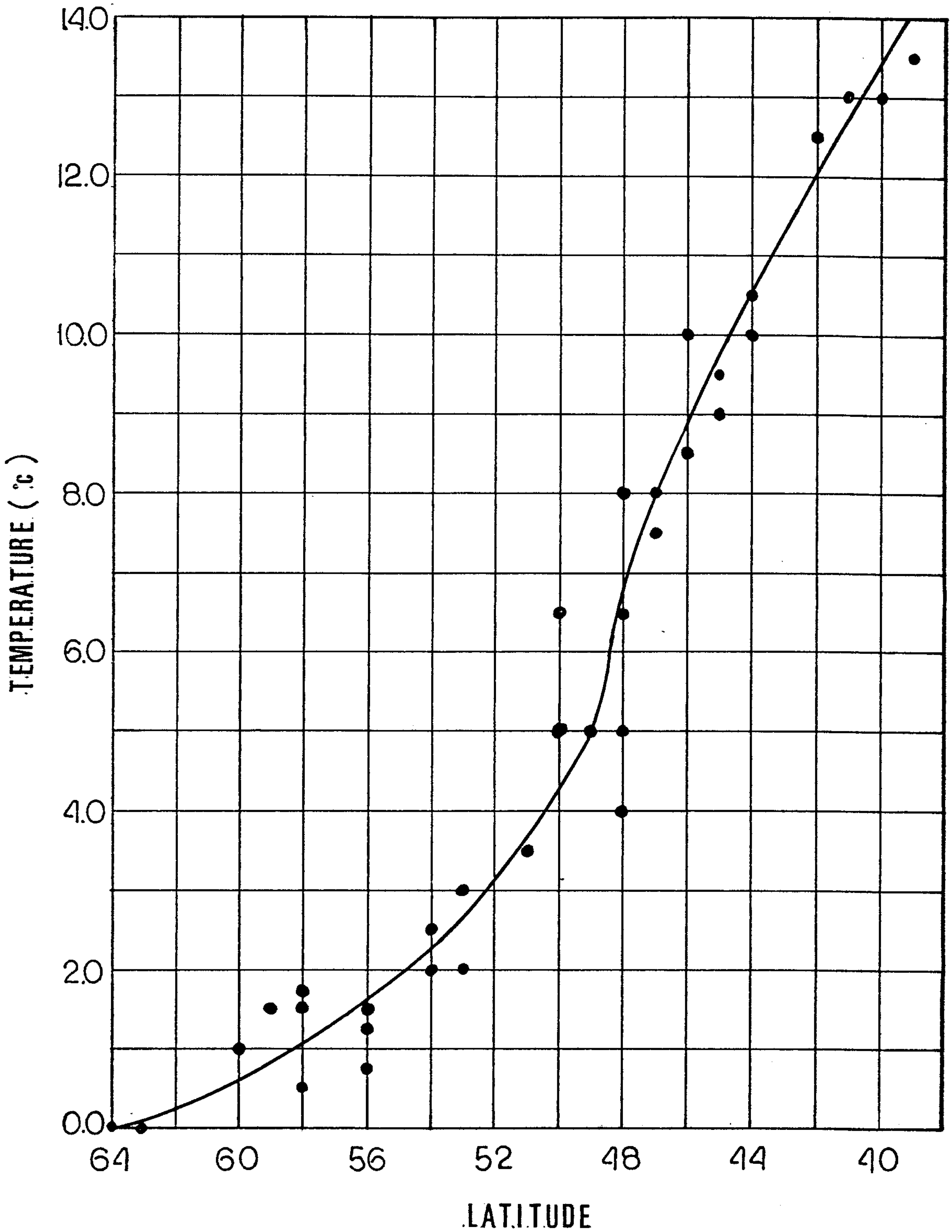

Figure 4: Annual mean surface water temperature as a function of latitude.

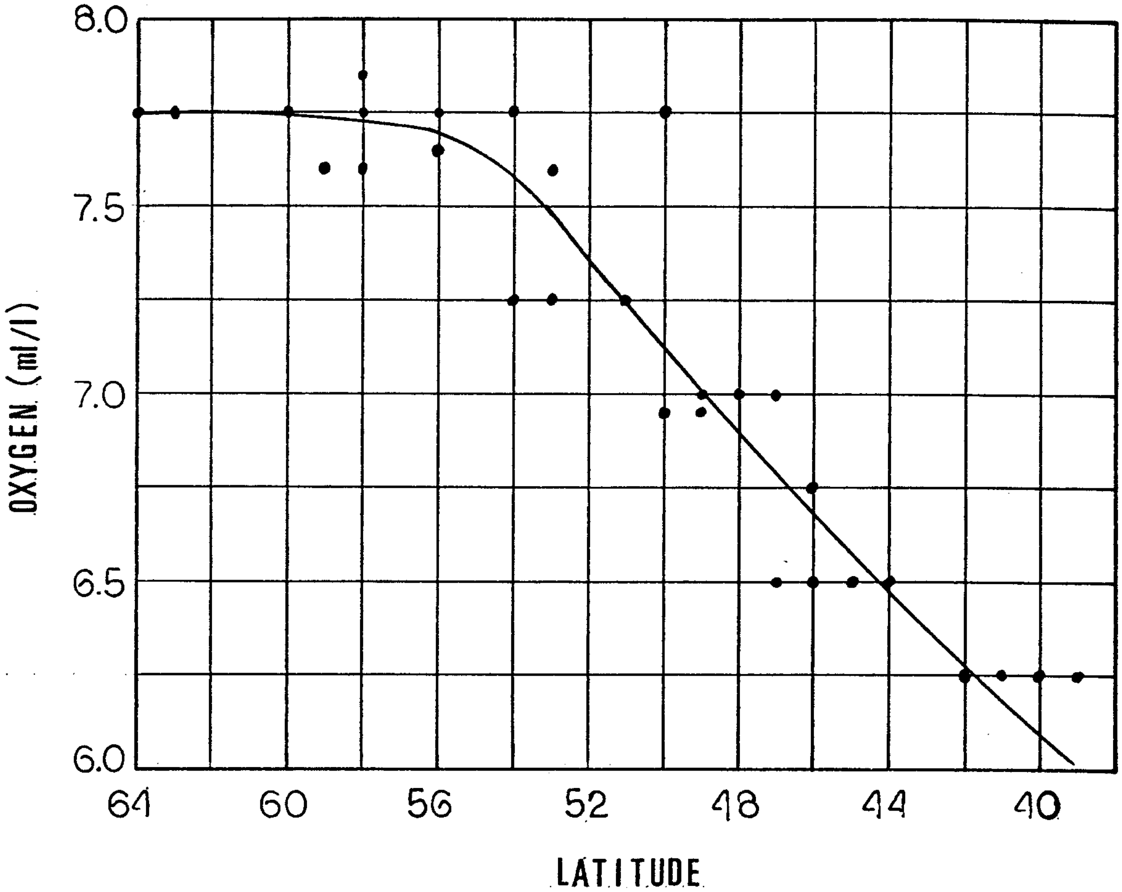

Figure 5: Annual mean surface water oxygen level as a function of latitude.

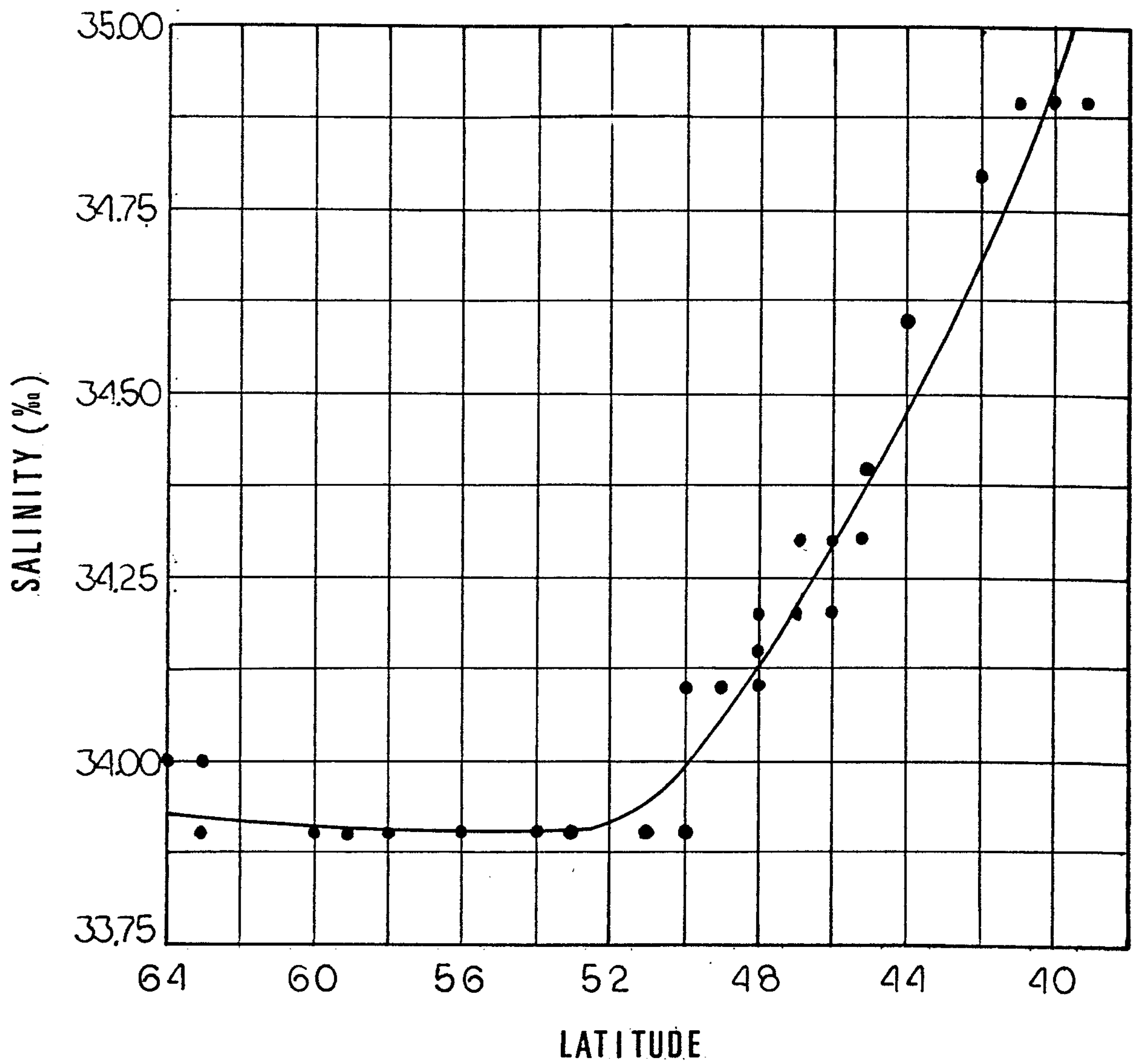

Figure 6: Annual mean surface water salinity as a function of latitude.

Discussion

If surface water temperature has the greatest effect on the relative abundance of silicoflagellate genera, then similarities should exist in the way it relates to the Dictyocha/Distephanus ratio in a given water mass. In studying the relationship between temperature and the Dictyocha/Distephanus ratio with respect to latitude, general similarities are noticeable between these two variables. Both variables change at a lower rate south of the Antarctic Convergence than north of it, and both are greatly affected by the presence of the Antarctic Convergence. However, south of the Antarctic Convergence, the Dictyocha/Distephanus ratio does not increase as much as the change in temperature would indicate. This may be attributed to a number of factors. For example, more base data may prove that the relationship is actually closer than is shown here, and the fact that the ratio is an exact parameter whereas temperature is an average parameter. However, there is the possibility other environmental factors may limit the number of Dictyocha south of the Antarctic Convergence.

Salinity and oxygen levels remain at a fairly constant level south of the Antarctic Convergence, and it is possible other ecologic factors such as nutrient availability, do too. Even though these variables change very little numerically compared to the change in temperature, this does not necessarily mean they have a small effect on the silicoflagellate genera that are present. Each silicoflagellate genera probably has an optimum environmental range in which it flourishes. Gemeinhardt (1934) gave optimum salinity ranges of 33.5 ‰-34.7 ‰ for _Dictyocha_ and 33.5 ‰ - 34.4 ‰ for _Distephanus_. Therefore, the large increase in mean annual temperature compared to the increase of the _Dictyocha_/_Distephanus_ ratio south of the Antarctic Convergence, may be the result of a lack of variability that prevents the ratio from increasing at an equal rate.

Fluctuations of individual variables with Dictyocha/ Distephanus ratio

Temperature As A Function Of Ratio

The temperature curve based on the _Dictyocha_/ _Distephanus_ ratio in this study (Figure 7) correlates very well with the temperature curve developed by Ciesielski (1974) (Figure 1). _Dictyocha_/_Distephanus_

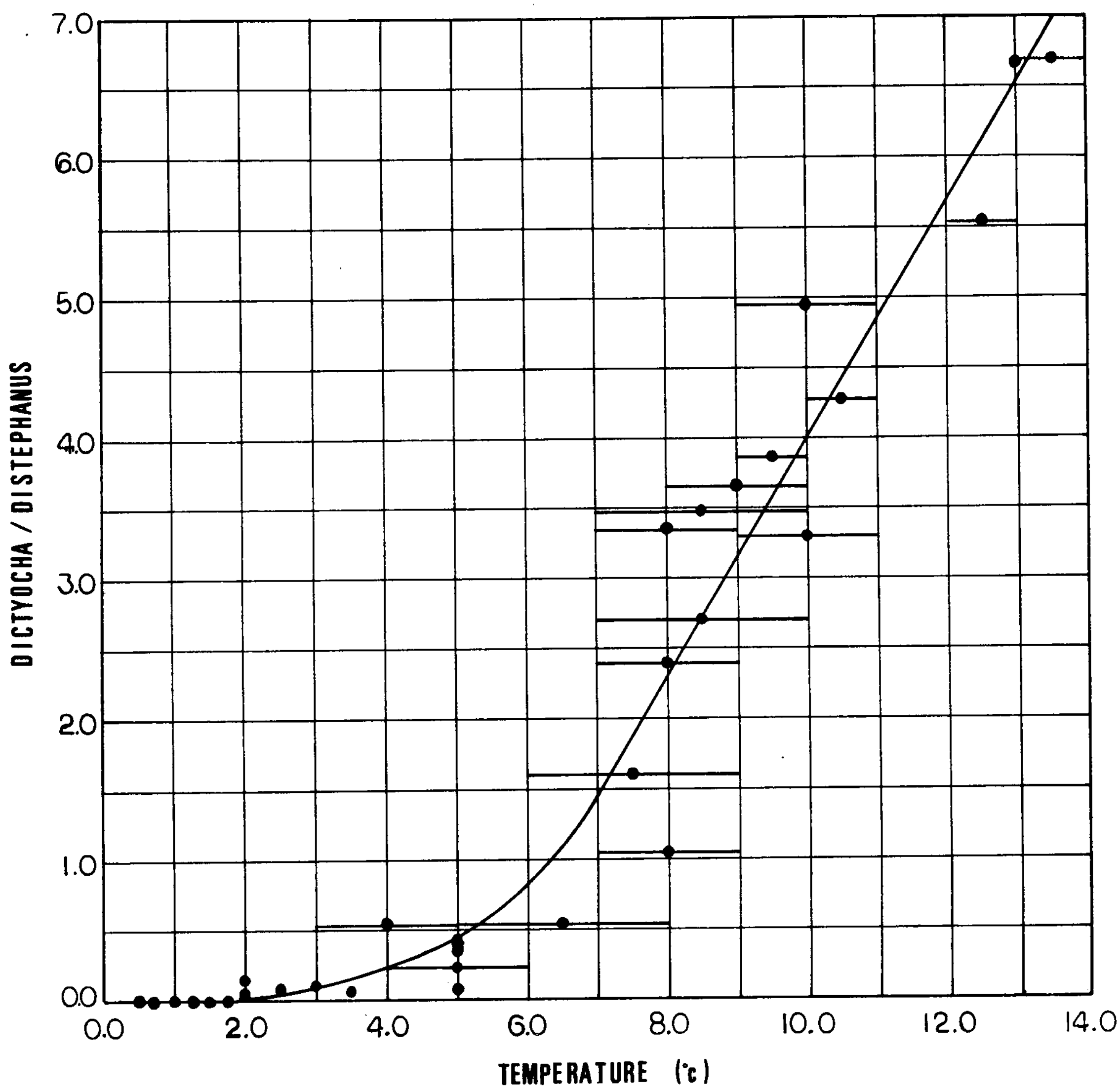

Figure 7: Surface sediment Dictyocha/Distephanus ratio as a function of annual mean surface water temperature. The error bars reflect the possible temperature range at each core area determined from surrounding observation stations.

ratios of 0.00 are correlated with temperatures less than 2.0°C. Ratios between 0.0 and 0.50 are correlated with temperatures of 2.0°C to 5.0°C. Ratios between 0.50 and 2.00 are correlated with temperatures of 5.0°C to 8.0°C, and ratios from 2.0 to 6.7 are correlated with temperatures of 8.0°C to 13.5°C.

The mathematical relationship between temperature and the Dictyocha/Distephanus ratio can be expressed as a second order polynomial in which the Dictyocha/Distephanus ratio is a function of the square of the temperature. The relationship is:

$$R=k_1T^2 + k_o$$

where R is the ratio, T the temperature, and (k) the coefficeints.

Oxygen As a Function of Ratio

The mean annual surface water oxygen level correlates inversely in an exponential manner with the Dictyocha/Distephanus ratio. Ratios of 0.0 - 0.5 are associated with oxygen levels of 7.0 - 8.0 ml/l and ratios from 0.5 - 7.0 are associated with oxygen levels of 6.0 - 7.0 ml/l (Figure 8).

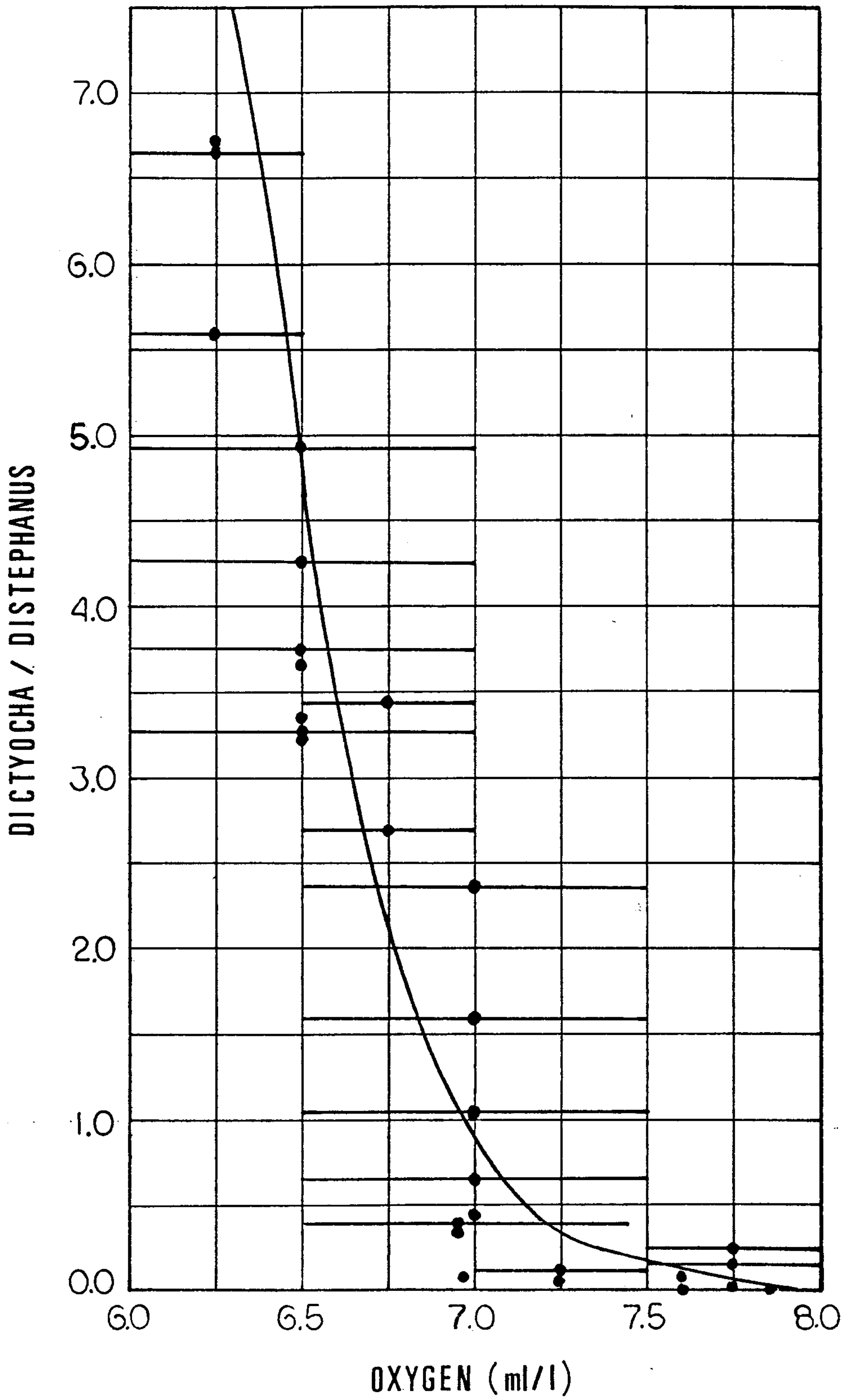

Figure 8: Surface sediment <u>Dictyocha</u>/<u>Distephanus</u> ratio as a function of annual mean surface water oxygen level. Error bars reflect possible oxygen levels at each core area determined from surrounding observation stations.

Mathematically, the *Dictyocha/Distephanus* ratio is a function of the inverse cube of the oxygen level. The relationship can be expressed as:

$$R=1/X^3+ k_o$$

where R is the ratio, X the oxygen and the coefficient (k).

Salinity as a Function of Ratio

Because the mean annual surface water salinity level has such a small numerical change throughout the study area, it may be interpreted as a linear function with the *Dictyocha/Distephanus* ratio. Salinity is, however, affected by the Antarctic Convergence and in actuality has an exponential relationship with the ratio (Figure 9). The actual mathematical relationship has not been determined here, however it is of a third order polynomial form.

Mean salinity levels of 33.9 $^o/oo$ are associated with ratios of 0.25 and less. Mean salinity levels of 34.1 $^o/oo$ are correlated with ratios of 0.25 - 0.50, and salinity levels greater than 34.1 $^o/oo$ are correlated with ratios of 0.50 and greater.

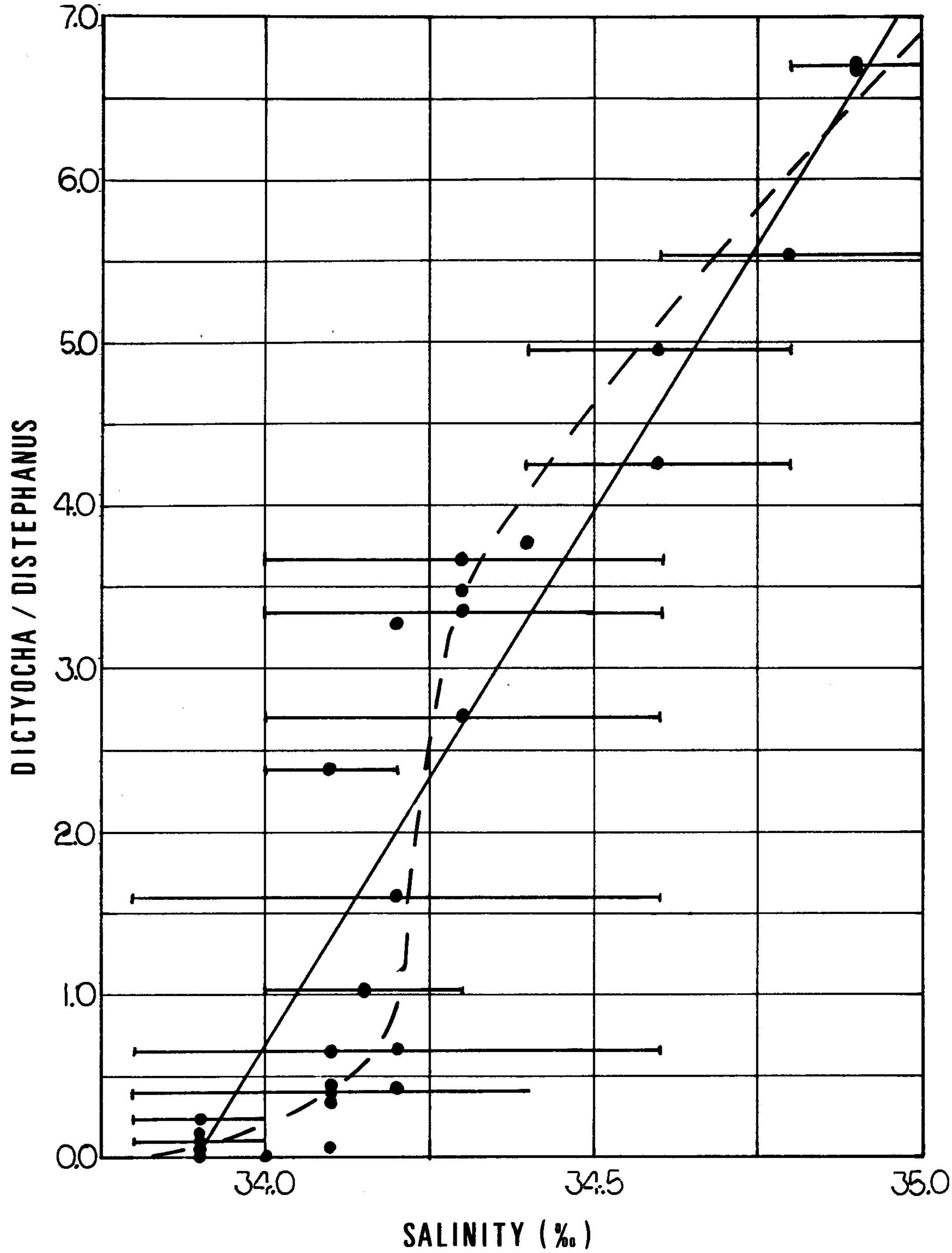

Figure 9: Mean annual surface water salinity as a function of surface sediment Dictyocha/ Distephanus ratio. Solid line is the linear relationship, dashed line is the actual relationship. Error bars reflect the possible salinity levels at each core area determined from surrounding observation stations.

The multiple regression analysis

The Regression Equation

A multiple regression analysis was used as a method to calculate coefficients for a regression equation that will accurately predict surface water temperatures by using Dictyocha/Distephanus ratios. The analysis can take into consideration the possible effects of the other ecological variables that may alter the relationship between temperature and the Dictyocha/Distephanus ratio.

A stepwise multiple regression analysis available in SPSS (Statistical package for the Social Science) by Nie, Bent, and Hull, (1970), was used in this study. In an analysis of this type, the independent variables that are proven to be non-significant are removed from the model. It does this by comparing the variable entered first, which was chosen by a simple correlation matrix, with the variable entered second, which was selected by using partial correlation coefficients. The order in which the variables were entered is then reversed to examine the contribution the first variable would have made if the second variable had been entered first. The next variable is then selected by using the partial correlation coefficients, and this variable is compared to the first two for its contribution. By using the partial F- distribution, it rejects those variables that are proven to be non-significant in the model. This selection of variables continues until no more are admitted into the equation and no more are rejected.

The stepwise multiple regression analysis also calculates the regression coefficients and a number of measures to test the significance of the regression.

The simplest form of regression analysis is a linear regression between two variables. The prediction equation is:

$$Y=K_1X+k_0$$

where Y is the dependent variable, X is the independent variable, k_1 is the coefficient for the slope of the line, and k_0 is the coefficient for the Y-intercept. In a multiple regression where two or more independent variables are significant in the model, the equation is expanded to:

$$Y=k_0+k_1X_1+k_2X_2+ \ . \ . \ .+k_nX_n$$

for n variables (X) with their respective coefficients (k). Many types of transformations may also be used for non-linear models. Some of these include the use of logarithms, exponents, and polynomials.

In this study the *Dictyocha/Distephanus* ratio was chosen as the dependent variable, and temperature, salinity, and oxygen were chosen as the independent variables. Because temperature shows the greatest amount of variation, it is treated as being more statistically significant than salinity and oxygen. Since temperature has a curved relationship with the *Dictyocha/Distephanus* ratio, then a transformation must be used to approximate the curve. A linear model would predict temperatures accurately only for ratios that are extremely low or extremely high because it cannot account for the curved area. Since the *Dictyocha/Distephanus* ratio is a function of the square of the temperature, then a second order polynomial transformation may be used as an approximation. The equation is:

$$R=k_3T^2+(k_2S+k_1X)+k_0$$

where R is the ratio, T the temperature, S the salinity, and X the oxygen with their respective coefficients (k). Because salinity and oxygen have such a small change numerically, they are treated as being linear in this model.

To predict temperatures using Dictyocha/ Distephanus ratios, the equation must be transformed to:

$$T=\left(\frac{R-(k_2S+k_1X)-k_0}{k_3}\right)^{\frac{1}{2}}$$

Results

Overall the predicted temperatures are usually to within $\pm 2.0^{\circ}$C of the observed temperatures (Table 3). Because the relative consistency of the Dictyocha/Distephanus ratio, oxygen, and salinity south of the Antarctic Convergence, the range of the predicted temperatures are less than the range of the observed temperatures. This results in the predicted temperatures being grouped between 2.0°C and 4.0°C when in actuality, the temperatures vary from -0.5°C to 5.0°C. Therefore, this equation cannot account for the variance in temperature at latitudes south of

53° - 56°S latitude. However, north of the Antarctic Convergence where all variables change with latitude, the equation accurately portrays the observed temperature curve and consistently predicts temperatures to within $\pm 2.0^{\circ}C$ (Figure 10).

Use for Paleotemperature Determinations

To use silicoflagellates for paleotemperature determinations, it must be assumed the silicoflagellate genera in the geologic epoch of the sediment being studied respond to ecological variables in the same way they respond in Recent sediments. Also, there are less living silicoflagellate species in Recent sediments than in older sediments, therefore, the use of this technique should be limited to Pliocene and Pleistocene sequences because older sequences contain a high percentage of taxa which are now extinct, (Ciesielski, 1974).

Even though this equation successfully predicts surface water temperatures to within $\pm 2.0^{\circ}C$ by using the Recent surface sediment cores in this study, it should be used with caution when applied for paleo-temperature inferences in Plio-Pleistocene sediments.

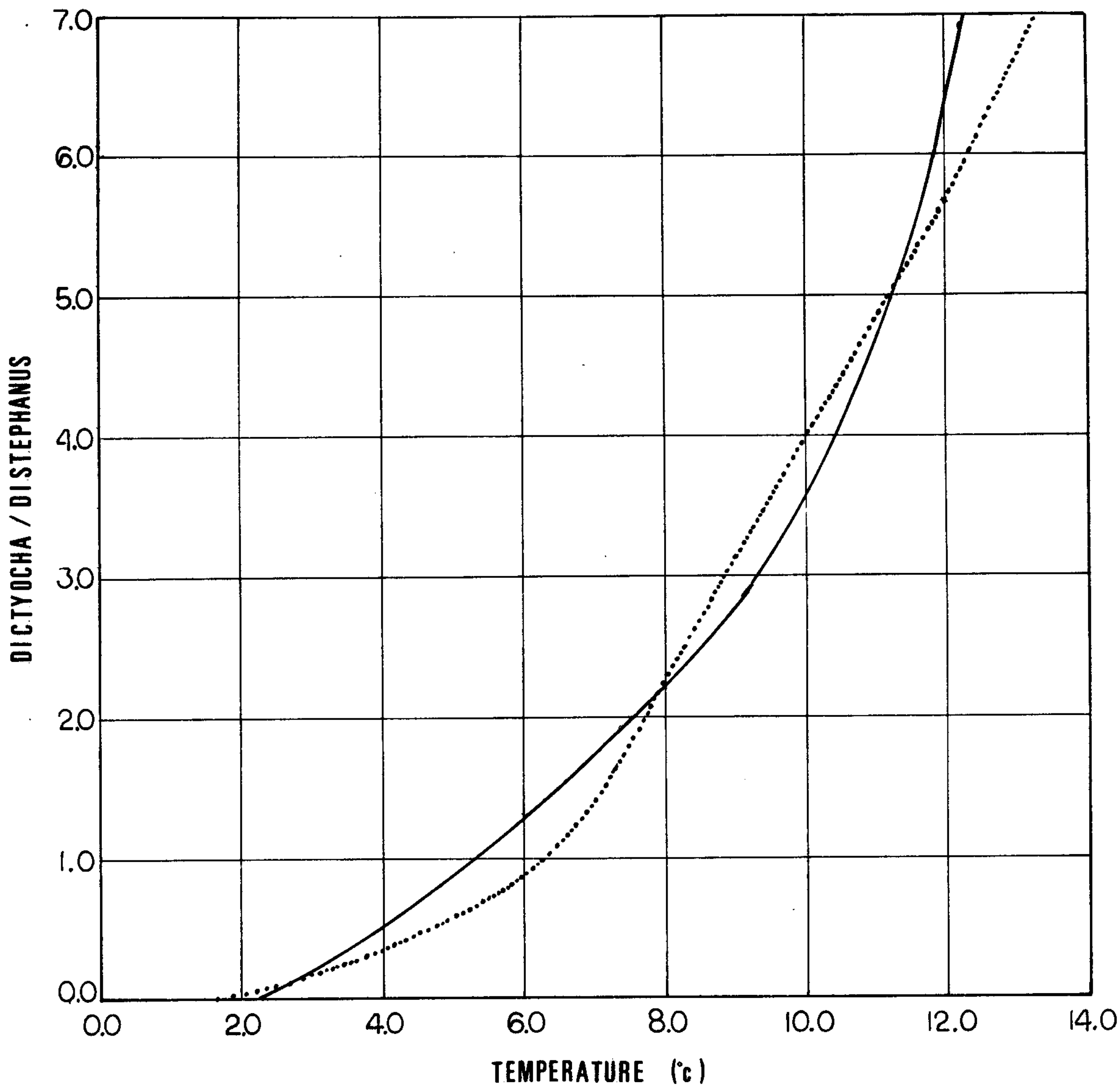

Figure 10: Observed temperature curve (dotted) as compared to the temperature curve generated from the multiple regression equation (solid).

Little is known about the ecology of silicoflagellates and what factors govern their relative generic abundances. There is an obvious correlation with temperature, but discrepencies exist as to the exact temperatures in which each genera flourishes. The reasons for these differences have yet to be resolved, therefore, an exact correlation with temperature cannot be used for paleoclimatic purposes worldwide.

In this particular area, the coefficients for the equation need to be refined by studying more core samples at closer intervals latitudinally. Variables that may influence the Dictyocha/Distephanus ratio fluctuate from east to west. Therefore, core samples that are studied from a wide area longitudinally yield data which does not precisely portray the exact effect of the Antarctic Convergence and the relationship between the variables. Individual tracks of samples taken at very close intervals from south to north, latitudinally, over the Antarctic Convergence will yield data that more accurately reflects the behavior of Dictyocha and Distephanus with temperature. A more precise temperature curve can then be determined as well as a multiple regression equation.

Conclusion

This is a beginning in quantifying the use of silicoflagellates for paleotemperature determinations. This equation cannot be used to predict paleotemperatures to within $\pm 2.0^{\circ}C$ in Plio-Pleistocene sediments as it does in Recent sediments, but it is useful for predicting general paleotemperature ranges. As more surface sediment samples are obtained, and as our knowledge of silicoflagellates increases, paleotemperature predictions using this method can only be improved.

TABLES: 1-4

TABLE 1: SUMMARY TABLE

CORE	APPROX. LAT.	APPROX. LONG.	DEPTH (F)	OXYGEN Ml/l	SALINITY $^{o}/oo$	TEMP. ^{o}C	DICT./ DIST.	NO. COUNTED
Tc 37-12A	64 S	136 E	1230	7.5-8.0	34.00	-0.50	0	47
Ph 50-12A	63 S	130 E	2310	7.5-8.0	34.00	-.5-0.0	0	143
Ph 50-11A	63 S	125 E	2231	7.5-8.0	33.8-34.0	-.80-0.0	0	3
Ph 50- 9A	60 S	110 E	2381	7.5-8.0	33.8-34.0	00-2.0	0	200
Tc 45-45	59 S	115 E	2414	7.5-7.7	33.8-34.0	1.0-2.0	0	69
Tc 44-45	58 S	133 E	2493	7.5-8.0	33.8-34.0	1.5-2.0	0	200
Tc 45-54	58 S	115 E	2427	7.5-7.7	33.8-34.0	1.0-2.0	0	201
Ph 50- 8A	58 S	105 E	2403	7.5-8.0	33.8-34.0	1.0-2.0	0	208
Ph 54- 3	58 S	83 E	2160	7.7-8.0	33.8-34.0	0.0-1.0	0	28
Ph 49-10	57 S	95 E	2317	7.5-7.8	33.8-34.0	0.5-1.0	.01	211
Tc 45-40	56 S	113 E	2300	7.5-8.0	33.8-34.0	1.0-2.0	0	222
Ph 50- 7A	56 S	105 E	1739	7.5-8.0	33.8-34.0	1.0-2.0	.01	207
Ph 54- 2	56 S	83 E	2510	7.6-7.9	33.8-34.0	0.5-2.0	.01	84
Ph 54- 1	54 S	84 E	2525	7.4-7.8	33.8-34.0	1.0-3.0	.06	57
Ph 49- 9	54 S	95 E	2109	7.5-8.0	33.8-34.0	1.0-3.0	.15	215
Ph 50- 6A	54 S	105 E	2010	7.0-7.5	33.8-34.0	2.0-3.0	.09	200
Ph 54- 4	53 S	124 E	2380	7.0-7.5	33.8-34.0	2.0-4.0	.10	205
Ph 50- 5A	51 S	105 E	1793	7.0-7.5	33.8-34.0	3.0-4.0	.08	200
Tc 50- 7A	50 S	105 E	1739	7.5-8.0	33.8-34.0	4.0-6.0	.24	203
Tc 49- 5A	50 S	110 E	1899	6.5-7.4	33.8-34.4	4.0-6.0	.40	219
Tc 49-25A	49 S	95 E	1824	6.5-7.5	33.8-34.4	4.0-6.0	.44	200
Tc 45-67	49 S	114 E	1790	6.5-7.4	33.8-34.4	4.0-6.0	.07	109
Ph 54- 7	49 S	125 E	2300	6.5-7.4	33.8-34.4	5.0-8.0	.35	31
Tc 49-17A	48 S	90 E	1915	6.5-7.5	33.8-34.6	4.0-6.0	.42	201
Tc 49-24A	48 S	95 E	1757	6.5-7.5	33.8-34.6	3.0-5.0	.65	200
Tc 50- 6A	48 S	105 E	1671	6.5-7.5	33.8-34.4	5.0-8.0	.63	205
Ph 54- 8	48 S	126 E	2510	6.5-7.5	34.0-34.3	7.0-9.0	1.04	155
Tc 45-74	48 S	114 E	2080	6.5-7.5	34.0-34.2	7.0-9.0	2.39	200
Ph 49-12	47 S	100 E	1562	6.5-7.5	33.8-34.6	6.0-9.0	1.60	206
Tc 49- 4A	47 S	110 E	1951	6.0-7.0	34.0-34.6	7.0-9.0	3.35	200
Tc 45-77	46 S	114 E	2081	6.0-7.0	34.0-34.4	9.0-11.0	3.28	201
Tc 49-43	46 S	100 E	1679	6.5-7.0	34.0-34.6	7.0-10.0	2.70	200
Tc 49-44A	46 S	100 E	1894	6.5-7.0	34.0-34.6	7.0-10.0	3.48	206
Tc 49- 3A	45 S	110 E	2289	6.0-7.0	34.0-34.6	8.0-10.0	3.66	205
Tc 49-45A	45 S	100 E	1915	6.0-7.0	34.2-34.6	9.0-10.0	3.76	200
Tc 49-46A	44 S	100 E	1973	6.0-7.0	34.4-34.8	9.0-11.0	4.94	202
Tc 50- 4A	44 S	105 E	2051	6.0-7.0	34.4-34.8	10.0-11.0	4.26	200
Tc 49-49A	42 S	100 E	2169	6.0-6.5	34.5-35.0	12-13	5.54	157
Tc 49.50A	41 S	100 E	2219	6.0-6.5	34.8-35.0	12.5-13.5	6.69	200
Ph 50- 1A	40 S	105 E	2326	6.0-6.5	34.8-35.0	12.5-13.5	9.63	202
Tc 49-52A	39 S	100 E	2274	6.0-6.5	34.8-35.0	13.0-14.0	6.70	154

Table 2: STATISTICAL DATA USED IN STEPWISE MULTIPLE REGRESSION ANALYSIS

R	T	O	S
0.00	-0.50	7.75	34.00
0.00	-0.25	7.75	34.00
0.00	0.00	7.75	33.90
0.00	1.00	7.75	33.90
0.00	1.50	7.60	33.90
0.00	1.75	7.75	33.90
0.00	1.50	7.75	33.90
0.00	1.50	7.75	33.90
0.01	1.50	7.75	33.90
0.01	0.75	7.65	33.90
0.01	1.25	7.65	33.90
0.06	1.50	7.60	33.90
0.15	1.50	7.75	33.90
0.09	2.50	7.25	33.90
0.10	3.00	7.25	33.90
0.08	3.50	7.25	33.90
0.24	5.00	7.75	33.90
0.44	5.00	7.00	34.10
0.40	5.00	6.95	34.10
0.35	5.00	6.95	34.10
0.42	5.00	7.00	34.12
0.65	4.00	7.00	34.12
0.63	6.50	7.00	34.10
1.04	8.00	7.00	34.15
2.39	8.00	7.00	34.10
1.60	7.50	7.00	34.42
3.35	8.00	6.50	34.30
3.28	10.00	6.50	34.20
2.70	8.50	6.75	34.30
3.48	8.50	6.75	34.30
3.66	9.00	6.50	34.30
3.76	9.50	6.50	34.40
4.94	10.00	6.65	34.60
4.26	10.50	6.65	34.60
5.54	12.50	6.25	34.80
6.69	13.00	6.25	34.90
9.63	13.00	6.25	34.90
6.70	13.50	6.25	34.90

R - Dictyocha/Distephanus

T - Annual Mean Surface Water Temperature

O - Annual Mean Surface Water Oxygen Level

S - Annual Mean Surface Water Salinity Level

TABLE 3: SURFACE WATER TEMPERATURE PREDICTIONS USING THE MULTIPLE REGRESSION EQUATION:

$$T=\left(\frac{R-(2.68S+.39X)-94.02}{.03}\right)^{\frac{1}{2}}$$

S - Salinity R - Ratio
X - Oxygen
T - Temp.

CORE	RATIO	OBSERVED T	PREDICTED T	DIFFERENCE
Tc 37-12A	0.00	-0.50	2.00	-2.50
Ph 50-12A	0.00	-0.25	2.00	-2.25
Ph 50- 9A	0.00	1.50	2.24	-0.74
Tc 44-17	0.00	1.75	2.24	-0.49
Tc 45-54	0.00	1.50	2.65	-1.15
Ph 50-11A	0.00	0.00	2.24	-2.24
Ph 50- 8A	0.00	1.00	2.24	-1.24
Ph 50- 7A	0.01	1.50	2.31	-0.81
Ph 54- 2	0.01	1.25	2.58	-1.33
Tc 45-40	0.00	1.50	2.24	-0.74
Ph 49-10	0.01	0.75	2.31	-1.56
Ph 54- 1	0.06	1.50	3.00	-1.50
Ph 49- 9	0.15	1.50	3.16	-1.66
Ph 50- 6A	0.09	2.50	3.74	-1.24
Ph 54- 4	0.10	3.00	3.79	-0.79
Ph 50- 5A	0.08	3.50	3.70	-0.20
Tc 50- 7A	0.24	5.00	3.60	1.40
Tc 49-25A	0.44	5.00	3.36	1.64
Ph 54- 7	0.35	5.00	3.00	2.00
Tc 49- 5A	0.40	5.00	3.27	1.73
Tc 49-17A	0.42	5.00	1.29	3.71
Tc 49-24A	0.65	4.00	3.05	0.95
Tc 50- 6A	0.63	6.50	4.24	2.26
Ph 54- 8	1.04	8.00	5.20	2.80
Tc 45-74	2.39	8.00	8.74	-0.74
Ph 49-12	1.60	7.50	6.40	1.10
Tc 49- 4A	3.35	8.00	9.88	-1.88
Tc 45-77	3.28	10.00	10.16	-0.16
Tc 49-43	2.70	8.50	8.54	-0.04
Tc 49-44	3.48	8.50	9.95	-1.45
Tc 49- 3A	3.66	9.00	10.39	-1.39
Tc 49-45A	3.76	9.50	10.08	-0.58
Tc 49-46A	4.94	10.00	11.02	-1.02
Tc 50- 4A	4.26	10.50	9.93	0.57
Tc 49-49A	5.54	12.50	11.36	1.14
Tc 49-50A	6.69	13.00	12.58	0.42
Ph 50- 1A	9.63	13.00	16.01	-3.01
Tc 49-52A	6.70	13.50	12.60	1.5

TABLE 4: SUMMARY OF STATISTICS

Summary Table of Statistics After Last Regression

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA	STD. ERROR B	F
Temperature	0.961	0.923	0.923	0.961	0.031	0.691	0.008	14.697
Salinity	0.965	0.930	0.007	0.949	2.777	0.362	1.382	4.040
Oxygen	0.965	0.932	0.001	-0.847	0.417	0.089	0.489	0.727
					94.02 (CONSTANT)			

Correlation Coefficients

	R	T2	0	S
R	1.000	0.962	-0.849	0.949
T2	0.962	1.000	-0.893	0.962
0	-0.849	-0.893	1.000	-0.881
S	0.949	0.962	-0.881	1.000

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